

1     **Determining the Effective Factors Leading to Incidence of Human**  
2     **Error Accidents in Industrial Parks Construction Projects: Results of**  
3             **a Fuzzy Delphi Survey**

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6                     **Adel Rafieyan**

7     Department of Civil Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran;  
8                     [a.rafieyan@khuisf.ac.ir](mailto:a.rafieyan@khuisf.ac.ir)

9  
10                    **Hadi Sarvari (Corresponding author)**

11     Department of Civil Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran;  
12                    [h.sarvari@khuisf.ac.ir](mailto:h.sarvari@khuisf.ac.ir)

13  
14                    **Michael Beer**

15     Institute for Risk and Reliability, Leibniz Universität Hannover, Callinstrasse 34, 30167  
16                    Hannover, Germany; [beer@irz.uni-hannover.de](mailto:beer@irz.uni-hannover.de)

17  
18                    **Daniel W.M. Chan**

19     Dept. of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom,  
20                    Kowloon, Hong Kong, China; [daniel.w.m.chan@polyu.edu.hk](mailto:daniel.w.m.chan@polyu.edu.hk)

21  
22                    **Corresponding author Email: [h.sarvari@khuisf.ac.ir](mailto:h.sarvari@khuisf.ac.ir)**

23 **Determining the Effective Factors Leading to Incidence of Human Error Accidents in**  
24 **Industrial Parks Construction Projects: Results of a Fuzzy Delphi Survey**

25

26 **Abstract**

27 The implementation of construction projects is always associated with several incidents for various  
28 reasons. Previous research studies advocated that human errors are one of the main causes of  
29 accidents in these projects. This paper aims to determine the effective factors leading to the  
30 occurrence of accidents caused by human errors in Industrial Parks Construction Projects (IPCPs)  
31 based in Iran. For this purpose, four rounds of the fuzzy Delphi survey were conducted with the  
32 presence of fifteen experienced experts engaged in the HSEE (health, safety, environment and  
33 energy) department of Industrial Parks in Iran. The reliability and validity of the questionnaire  
34 were reviewed and confirmed. Based on the results of the Delphi survey, forty-one factors  
35 contributing to human errors in the implementation of IPCPs were determined and classified into  
36 nine main groups. The survey findings manifested that the identified effective factors have a strong  
37 effect on the occurrence of construction accidents caused by human errors. The results of this  
38 research study have provided various major project stakeholders and safety managers with a useful  
39 decision-aid tool to make more pragmatic decisions in managing, reducing and avoiding the  
40 occurrence of construction site accidents particularly caused by human errors associated with  
41 IPCPs.

42

43 **Keywords:** *Construction projects, Site safety, Human errors, Industrial Parks, Fuzzy Delphi*  
44 *technique, Iran.*

45 **1. Introduction**

46 The construction industry is one of the most dangerous industries in terms of work-related losses,  
47 injury rates, and workers' compensation (Muneeswaran et al., 2020). In the construction industry,  
48 injuries leading to death, serious occupational injuries and lost work time occur due to their unique  
49 nature and a high number of accidents cause severe human and financial damage to communities  
50 (Manu, 2021). Continuous changes in the work environment, use of various resources and tools,  
51 unsuitable working conditions, unsustainable employment and also unsuitable working  
52 environments are among the characteristics of the construction industry that cause accidents  
53 (Jahani, 2017). Some accidents cause physical damage and destruction of part of the project, which  
54 will hurt the work efficiency of other project staff. In this regard, paying attention to the principles  
55 of safety and prevention of accidents and diseases caused by work in worksites is a high priority  
56 in projects, especially large ones (Hoła and Szóstak, 2017). Therefore, it seems that there are no  
57 shortcomings in terms of legal principles, but in general, the statistics of work-related accidents in  
58 Iran compared to developed countries, show an unacceptable increase (Shao et al., 2019).  
59 According to reports, construction project accidents in Iran are in a higher rank compared to global  
60 scales (Mohseni et al., 2015). Now, according to the evaluation and research, it has been  
61 determined that most accidents are caused by negligence and on-observance of safety principles  
62 in the use of inappropriate machinery and equipment. Previous studies show that human error is  
63 one of the main causes of accidents in construction projects.

64 Construction projects involve remarkably diverse and complex activities, so such projects  
65 always carry many inherent risks during execution. Of course, these risks vary according to the  
66 conditions and environment of construction projects. For example, project risks and threats are  
67 different in urban and industrial environments (Ayhan and Tokdemir, 2020). Naturally, the

68 implementation of Industrial Parks construction projects (IPCPs) is associated with more  
69 complexities. Artisans and their social issues and expectations, and influential groups that are  
70 formally or informally sensitive about projects or their consequences, are among the items that  
71 complicate projects and the consequences of accidents. Physically limited space, the activity of  
72 industrial units, the high volume of light and heavy machinery traffic and the environment in which  
73 the project is implemented, enhance the complexity of implementation and accident prevention  
74 and increase its risk. Therefore, the effects and consequences of non-observance of safety and  
75 accidents of human error are very costly for stakeholders and sometimes will be irreparable. In  
76 this regard, benefiting from the experiences of previous projects is one of the most important  
77 measures to be taken in large construction projects in industrial environments (Goh and  
78 Ubeynarayana, 2017). By reducing and controlling human error, project risks and hazards can be  
79 greatly reduced (Shao et al., 2019). The purpose of learning from human error is to identify the  
80 source of risks and uncertainties, and their effects and provide an appropriate management  
81 response to these risks. Effective risk management includes four processes: risk identification, risk  
82 evaluation, risk response, and risk assessment and monitoring (Zhang et al., 2019). These  
83 processes aim to minimize the effects of risks on project objectives by eliminating or sharing risks.

84 A review of the research literature indicates that relatively extensive studies have been  
85 conducted in the fields related to human error and the factors affecting them in urban construction  
86 projects (Goh and Ubeynarayana, 2017; Shao et al., 2019; Zhang et al., 2019). While the research  
87 literature shows few studies on the factors affecting human error in industrial environments  
88 (Bussier and Chong, 2022; AbdulKarimi, 2018). Implementation of IPCP is very challenging due  
89 to the special working conditions and the specific type of building use (Chi et al., 2015). Therefore,  
90 this study to determine the factors affecting accidents caused by human errors in the IPCP in the

91 developing country of Iran tries to fill the gap between previous studies. Identifying the influential  
92 factors in accidents caused by human errors can play a key role in project management decisions.  
93 Therefore, the present study seeks to answer the following questions: (1) What factors are effective  
94 in the occurrence of accidents caused by human errors in the IPCPs? (2) What is the importance  
95 of the effective factors in the occurrence of accidents caused by human errors in the  
96 implementation of IPCPs? To answer the research questions, first, to accurately identify the factors  
97 affecting the events caused by human errors, the research literature was comprehensively  
98 reviewed. Then, using the Delphi survey technique in four different rounds, it was screened to  
99 match the factors extracted from the research literature with the IPCPs in Iran. Then the final  
100 identified factors were evaluated, and the most crucial factors were identified. The results of this  
101 study can help stakeholders as decision facilitators to make better decisions in managing, reducing,  
102 and avoiding human errors associated with these construction projects.

## 103 **2. Literature Review**

### 104 **2.1. Human errors in the construction industry**

105 Human error is part of our daily experience (Bussier and Chong, 2022). Occupational accidents  
106 have killed more than 300,000 people and injured more than 300 million worldwide each year  
107 (Amiri et al., 2014). According to researchers, the cost of occupational accidents in the  
108 construction industry may include up to 15% of the total cost (AbdulKarimi, 2018). Workplace  
109 safety is a major concern in many countries. Among the various industries, the construction sector  
110 is known as the most dangerous workplace. Construction accidents not only cause human suffering  
111 but also lead to a lot of financial losses. Incident analysis is essential to prevent the recurrence of  
112 similar incidents in the future and to prepare scientific risk control programs, (Zhang et al., 2019).

113 Studies of human factors show that human error is the reason for about 80% of major  
114 accidents that have affected safety, environment or ergonomics (Jahani, 2017). Many attempts  
115 have been made to define and classify human error. For example, Tixier et al. (2017) have defined  
116 error as an unauthorized action when the permissible operating limits are defined by the system.  
117 One of the most important classifications that have been accepted since its introduction as a  
118 suitable model for describing human function is the model proposed by Reisen (1990). He  
119 proposed an error modeling system based on the classification of Skill, Knowledge and Rule (S-  
120 K-R)-Based Behavior (Toole et al., 2017). Human error must be considered beyond tangible  
121 events. Errors in economic planning or military orders should also be investigated and analyzed in  
122 their place and depending on the intended purpose (Lee et al., 2018).

123 Sudani (2018) stated that many events occur in the world every year. Some of these accidents  
124 lead to damage to the environment and others lead to harm to humans. Environmental disasters,  
125 such as the release of various pollutants, affect water, soil, and air. Occupational accidents  
126 occurring due to non-compliance with health and safety principles can threaten people's health,  
127 disability and even death in acute cases. Accidents are usually the result of unsafe conditions or  
128 unsafe acts. In general, financial, or human losses are the negative consequences of industrial  
129 accidents.

130 Errors can impose direct and indirect costs on organizations. In such a way that some of the  
131 incurred expenses cannot be reimbursed by the insurance. Only direct costs may be paid by  
132 insurance companies and therefore other costs are imposed on the organization (Love et al., 2018).  
133 The consequences of human error can be from minor to very severe, in addition, they may vary  
134 from one situation to another, from one job to another, or from one piece of equipment to another.  
135 Concerning equipment, the consequences of human error may fall into three categories: (i)

136 equipment operation is stopped completely; (ii) the equipment operation is not completely stopped,  
137 and (iii) equipment operation delays are negligible. Human errors in engineering can be classified  
138 under different classifications. The seven common classifications are as follows: (1) maintenance  
139 errors; (2) operator errors; (3) design errors; (4) assembly errors; (5) inspection errors; (6) error  
140 management; and (7) participatory errors (Zhou et al., 2016).

## 141 **2.2. Factors affecting human errors in the construction industry**

142 According to the research literature review, various researchers in the field of human engineering  
143 have stated that many general factors significantly increase stress on a person and in turn lead to a  
144 significant deterioration in his reliability (Liao et al., 2018; Love et al., 2018). Some of these  
145 general factors are as follows: Poor health, the possibility of redundancy at work, working with  
146 people with unpredictable moods, serious financial problems, working under very high pressures,  
147 not having the right expertise to do the work in progress Performing, experiencing problems with  
148 a spouse or children or both, poor chances for promotion, and excessive demands on people in the  
149 workplace (Zhou et al., 2016). Past experiences show that there are many reasons for human error.  
150 Some important items include poor training, poor equipment design, poor motivation, complex  
151 work, poor equipment operation and maintenance methods, insufficient workplace lighting, poor  
152 management, etc. (Hasanzadeh et al., 2017).

153 In another study, Azhdari et al. (2017) investigated the causes of accidents caused by human  
154 error in maintenance operations in the petrochemical industry. They identified and documented  
155 nineteen different causes of human error. They classified the identified factors into four levels  
156 unsafe actions, unsafe supervision, preconditions for unsafe practices, and organizational effects.  
157 They acknowledged that increasing the effectiveness of staff training and improving employee  
158 performance monitoring have the greatest role in reducing the occurrence of human error events

159 in petrochemical maintenance operations, respectively. Similarly, Jahani, (2017) classified human  
160 errors leading to accidents in one of the cement factories into 4 categories. The results of this study  
161 show that most errors are associated with the first level, i.e., errors due to unsafe actions. They  
162 also cited skill-based error, poor industrial environment, inadequate monitoring, and poor resource  
163 management as important causes of error.

164 AbdulKarimi (2018) consider the lack of strong safety culture as the main reason for many  
165 accidents. Mohajeri (2017) have examined the four criteria of cost, quality, time, safety, and  
166 ergonomics to evaluate human errors in the implementation of a road construction project with  
167 emphasis on ergonomic principles. They identified and assessed a total of 20 risks of error. Salimi  
168 (2017) also acknowledged that the implementation of construction projects is always affected by  
169 many dangers such as: falls on people and equipment, injuries, burns, electric shocks, accidents,  
170 falls, etc. He stated that the incidence of these accidents in Iran is about three times the global  
171 average and often the feedback of these accidents is very heavy for projects.

172 Morais et al. (2018) have studied the analysis of human reliability of human actions and  
173 external factors through the project life cycle. They introduced factors such as inadequate skills,  
174 insufficient information, inadequate quality control, inadequate communication, inadequate  
175 working hours, design problems, management issues, social pressures, and inadequate task  
176 allocation as factors in the occurrence of human error. Shi et al. (2019) stated that considering the  
177 nature of construction activities, construction workers usually work in partnership; therefore,  
178 interpersonal effects among workers play a key role in shaping and influencing the safety  
179 behaviors of construction workers. Amiri et al. (2014) have examined occupational accidents in  
180 road construction projects. They cited factors such as improper driving of road construction



181 machinery, burnout, heat, poor hygiene, and collision with machinery as the most important causes  
182 of accidents in this type of project.

183 Xu et al. (2019) have reviewed the development of an incident learning model to assess the  
184 ability of construction workers during safety training. Improving the safety performance of  
185 construction workers lies strongly in the safety training and training of technologies, materials,  
186 and organizations. The results of their research also showed that age, experience, business, type of  
187 project, type of organization and site environment affect the characteristics and learning abilities  
188 of workers, which leads to various levels of safety perception, awareness, and performance (Chan  
189 et al, 2021). In addition, Dhalmahapatra et al. (2019) investigated the causes of crane accidents.  
190 Cranes serve in the manufacturing industry to transport materials in complex work environments.  
191 They stated that the complexity involved in machine-human interaction in the workplace puts it at  
192 risk. They also acknowledged that the number of accidents that occurred during construction and  
193 maintenance activities increased over the weekend (Saturday and Sunday).

194 A review of the research literature shows that although many studies have been conducted  
195 on human error, a comprehensive list of factors affecting the occurrence of human error in the  
196 manufacturing industry, especially in industrial areas, is not available. Therefore, to fill the gap in  
197 previous studies, this study seeks to determine the effective factors in the occurrence of accidents  
198 caused by human error in the IPCPs (Table 1). In this regard, based on a comprehensive review of  
199 the research literature, fifty-four effective factors in the incidence of human error were identified  
200 and categorized into seventeen groups, which were used as the first-round questionnaire of the  
201 Delphi technique (Table 2). This categorization is based on research background (previous  
202 research studies) and expert opinions.

203

**Table 1.** Examples of human errors-related studies based on a review of research literature

Location	Type of project	Techniques adopted	Number of human-related factors identified	References
Worldwide	Industrial sectors	Cognitive reliability and error analysis	53	Moura (2017)
Poland	Construction industry	Dynamic discreet process	15	Hoła and Szóstak (2017)
China	Construction industry	Bayesian networks and human factors analysis and classification system	35	Xia et al. (2018)
China	Construction industry	Dissipative structure	10	Liu et al. (2020)
Worldwide	Industrial sectors	Bayesian networks	39	Morais et al. (2020)
Iran	Industrial sectors	SWARA	41	Rafieyan et al. (2022)
China	Construction industry	Human factors analysis and classification system	27	Song et al. (2022)
Iran	Construction industry	Delphi survey technique	35	Chan et al. (2022)

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206

**Table 2.** Effective factors leading to the occurrence of human errors based on a review of

207

research literature

No.	Groups	Factors	References
1	Act at the wrong time	timing	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
2		duration	(Hollnagel, 1998, Moura, 2017)
3	The action of the wrong type	Force	(Hollnagel, 1998, Moura, 2017)
4		Space	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
5		Speed	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
6		Direction	(Hollnagel, 1998, Moura, 2017)
7	Acting on the wrong equipment	Wrong equipment	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
8	Action in the wrong place	Sequence	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
9	Observation	Missing observation	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
10		Wrong view	(Hollnagel, 1998, Moura, 2017)
11		Misdiagnosis	(Hollnagel, 1998, Moura, 2017)
12	Interpretation	Error detection	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
13		Wrong argument	(Hollnagel, 1998, Moura, 2017)
14		Decision error	(Hollnagel, 1998, Moura, 2017)
15		Delayed interpretation	(Hollnagel, 1998, Moura, 2017)
16		Incorrect prediction	(Hollnagel, 1998, Moura, 2017)

No.	Groups	Factors	References
17	Planning	Incomplete design	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
18		Prioritization error	(Hollnagel, 1998, Moura, 2017)
19	Temporary people in the project	Error retaining information	(Hollnagel, 1998, Moura, 2017)
20		Fear	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
21		Distractions	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
22		Fatigue	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
23		Work variety	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
24		Neglect	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
25		Stress	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
26		Physiological	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
27		Permanent people in the project	Functional defects
28	Improper learning		(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
29	Tendency to think in a certain way		(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
30	Equipment failure	Hardware failure	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
31		Software failure	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
32	Processes	Improper construction method	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
33	Information issues	access to information	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
34		Vague information	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
35		Incomplete information	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
36	Communications	Incomplete communication	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
37		Communication failure	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
38	Organizing	Failure to organize	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
39		Improper quality control	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
40		Management problem	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
41		Design failure	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
42		Social pressure	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
43	Training	Insufficient skills	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
44		Insufficient knowledge	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
45	Environmental conditions	Improper temperature	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
46		Inappropriate sound	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
47		Unfavorable weather	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
48		Inadequate lighting	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
49		Undesirable humidity	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
50		Adverse environmental conditions	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
51	Work conditions	type of employment	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
52		Irregular working hours	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
53		Inadequate team support	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
54		Improper work design	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)

### 208 **3. Research Methodology**

209 The present study was conducted to determine the effective factors in the occurrence of accidents  
210 caused by human error in the IPCPs by descriptive survey method. For this purpose, the effective  
211 factors in the occurrence of accidents caused by human error were first studied through the  
212 literature, then the list of factors was then reinforced using the four-phase fuzzy Delphi survey  
213 method - already used for similar research studies (see Khosravi et al., 2020).

#### 214 **3.1. Fuzzy Delphi Survey**

215 The members of the Delphi panel consisted of fifteen experts with more than 20 years of  
216 experience in the HSEE (health, safety, environment, and energy) department of Industrial Parks.  
217 There is no strong and explicit rule on how to select and hire professionals who respond to the  
218 Delphi questionnaire. However, it should be noted that the quality of experts is more important  
219 than their number (Khosravi et al., 2020). Hence, participants in the Delphi survey of experts and  
220 critics who must have sufficient knowledge and experience in a similar subject should have  
221 sufficient time to participate and effective communication skills (Lee et al., 2018). In terms of the  
222 number of specialists involved, this is usually less than 50 and often from 10 to 20 (Sarvari et al.,  
223 2021). The number of specialists depends on factors such as sample homogeneity, Delphi  
224 objective, the scope of difficulty, quality of decision, ability of the research team, internal and  
225 external credibility, data collection time, available resources and scope of the problem studied  
226 (Sarvari et al., 2019).

227 In the classical Delphi method, the opinions of experts are expressed in definite numbers,  
228 while experts use their mental variables to express opinions, and this indicates the probability of  
229 uncertainty in this situation. The probability of uncertainty is more compatible with fuzzy sets.  
230 Therefore, it is better to prepare the data in natural language from experts and analyze it using

231 fuzzy sets. For this purpose, Ishikawa et al. (1993) proposed a method to integrate the conventional  
232 Delphi method with a fuzzy theory called the fuzzy Delphi method. In this method, membership  
233 functions are used to show the opinion of experts. The advantage of the fuzzy Delphi method is  
234 that it considers each of the ideas and combines them to reach a group agreement (Chen and Lee,  
235 2013; Lee et al., 2018; Dabiri et al, 2022). The steps of this method are a combination of the  
236 conventional Delphi method and the analysis of the data of each step using the definitions of fuzzy  
237 set theory. Fuzzy numbers are used for expert fuzzy comments. Fuzzy numbers are fuzzy sets  
238 defined with numerical data in case of uncertainty about a phenomenon (Bui et al., 2020). The  
239 steps of the fuzzy Delphi method in the present study are as follows: (1) Identifying the research  
240 indicators using a comprehensive review of the theoretical foundations of the research: In the  
241 present study, the factors were identified based on a detailed and comprehensive review of the  
242 research literature; (2) Collecting the opinions of decision-making experts: At this stage, after  
243 identifying the group of experts, a decision-making group consisting of experts related to the  
244 research topic was formed and questionnaires were sent to determine the relationship between the  
245 identified indicators, where the linguistic variables were used to express the importance of each  
246 indicator. The triangular fuzzy method has been developed for expert systems, decision-making  
247 and risk evaluation, and it has been successful in use (Bui et al., 2020; Garg and Rani, 2022).  
248 Triangular fuzzy numbers have been used in this study and Table 3 shows linguistic terms and  
249 triangular fuzzy numbers used; (3) Verification and screening of indicators: This is done by  
250 comparing the obtained value of each index with the threshold value. The threshold value is  
251 calculated in several ways, which is the value of 0.7 as the threshold value. To do this, we must  
252 first calculate the triangular fuzzy values of expert opinions. Then, to calculate the mean value of  
253 n respondents' comments, their fuzzy means must be calculated. In the present study, the threshold

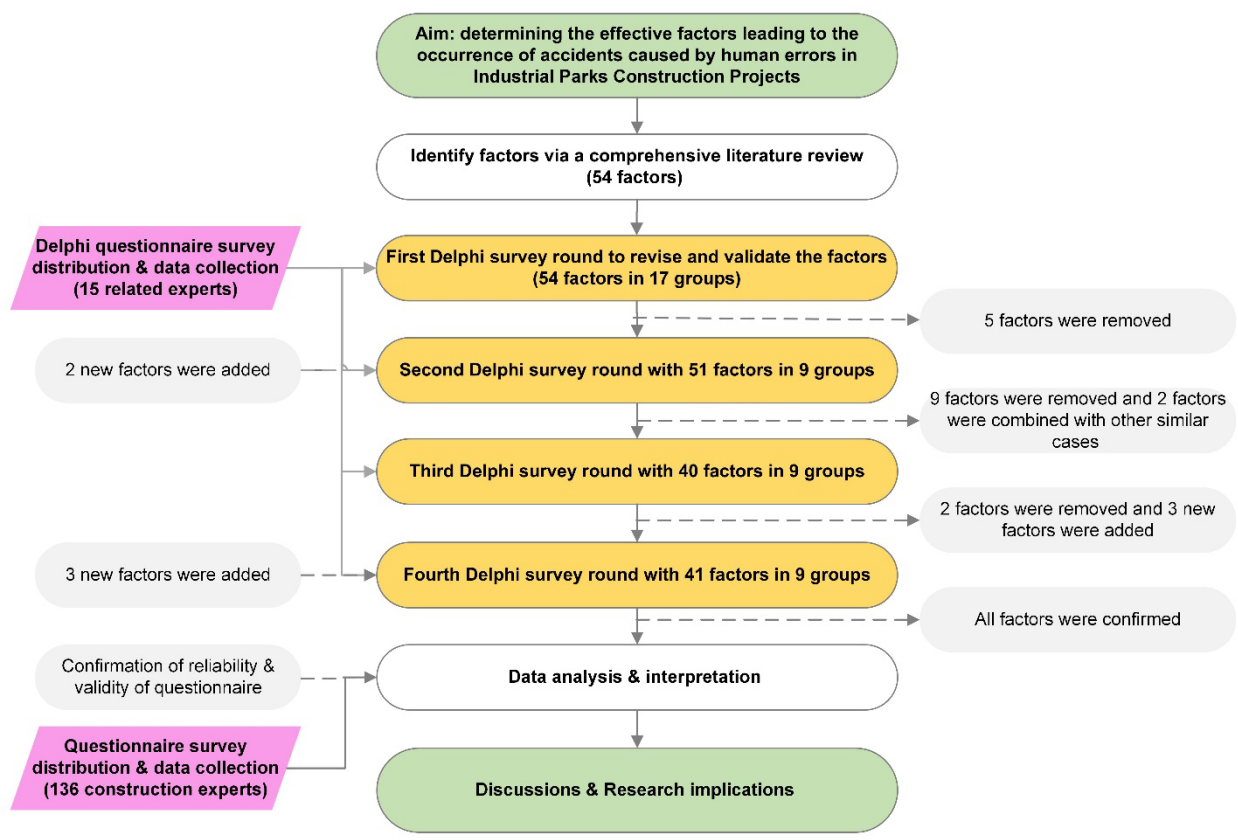
254 value is considered to be 0.8 to ensure; (4) The stage of consensus and completion of fuzzy Delphi:  
255 Consensus means that the respondents have reached a general decision about the factors and it is  
256 a stage after which nothing special happens in the groups (Rivera, 2018).

257 **Table 3.** Linguistic terms and triangular fuzzy numbers

Linguistic terms	Triangular fuzzy numbers
Extreme	(0.75, 1.0, 1.0)
Demonstrated	(0.5, 0.75, 1.0)
Strong	(0.25, 0.5, 0.75)
Moderate	(0, 0.25, 0.5)
Equal	(0, 0, 0.25)

258  
259 Based on previous studies and initial monitoring by researchers, the first stage Delphi  
260 questionnaire including fifty-four factors affecting the incidence of human error accidents was  
261 developed in seventeen groups. The steps were such that to determine the fact that the identified  
262 factors can be considered effective factors in the occurrence of accidents caused by human error  
263 in the Industrial Parks in Iran, fifteen experts were asked to present their opinion. The results of  
264 the first round indicated that out of fifty-four factors, five factors were removed from the  
265 questionnaire and two factors were added. In the second round, a new questionnaire with fifty-one  
266 factors was sent to the experts. In this round, forty-two factors had the necessary validity, but it  
267 was necessary to combine two factors with other similar cases and with close meanings. Thus, in  
268 the third round, a new questionnaire with forty factors was sent again to the experts. In this round,  
269 thirty-eight factors have the necessary validity and based on the new theories of experts, three  
270 items were added. In the fourth round, forty-one factors were sent back to the experts and then at  
271 this stage, all experts concluded that all forty-one identified factors could be identified as effective  
272 factors in the occurrence of accidents caused by human error in Iran's Industrial Parks. These forty-

273 one identified factors were classified into nine groups: wrong action, observations/interpretations,  
 274 planning/processes, equipment, organizing, individual activities, environmental conditions,  
 275 rescue, and technology. Figure 1 portrays the overall methodological framework for the study. The  
 276 final questionnaire was reviewed and approved based on face validity, content, and structure  
 277 (Table 4). The face validity of the questionnaire was confirmed based on the opinions of several  
 278 respondents, and the construct validity of the questionnaire was confirmed using the confirmatory  
 279 factor analysis coefficient. Judgmental criteria were also applied in scale purification with  
 280 statistical criteria (Wieland et al., 2017) which was implemented from the fuzzy Delphi survey.



281

282

**Figure 1.** Overall methodological framework for the study

**Table 4.** Results of the fourth stage of the fuzzy Delphi survey for the factors affecting the occurrence of accidents in IPCPs

No.	Groups	Factors	Descriptions/definitions
Q <sub>1</sub>	Wrong actions	Time	Wrong time action/wrong time allocation.
Q <sub>2</sub>		operational	Lack of attention to the observance of priority and delay in the implementation stages.
Q <sub>3</sub>		Tools	Using inappropriate tools to perform executive operations.
Q <sub>4</sub>		Place	Performing operations in the wrong place.
Q <sub>5</sub>	Observations/ Interpretations	Improper quality control	Failure to perform or defect in quality control of executive steps.
Q <sub>6</sub>		Ignore the symptoms	Signs of danger have been given but not considered.
Q <sub>7</sub>		False argument	The incorrect argument that leads to the accident.
Q <sub>8</sub>		Incorrect diagnosis/prediction	The main event has been predicted, but its side effects have been ignored.
Q <sub>9</sub>		Lack of access or defect in observations	Inability to access complete information for decision-making.
Q <sub>10</sub>		Delayed interpretation	The interpretations required to make the decision have been delayed.
Q <sub>11</sub>		Failure to perform the necessary controls	Failure to perform the necessary step controls.
Q <sub>12</sub>	Planning/Processes	Improper design	Choosing the wrong design according to the current situation.
Q <sub>13</sub>		Prioritization/scheduling error	Wrong prioritization in planning.
Q <sub>14</sub>		Improper construction method	The selected method is inappropriate.
Q <sub>15</sub>	Equipment	Equipment failure	Failure to perform timely repairs and maintenance.
Q <sub>16</sub>		Software error	Switching off the warning or error reporting systems.
Q <sub>17</sub>		Equipment deduction	Lack of proper equipment to perform executive operations or their wear.
Q <sub>18</sub>	Organizing	Improper chart	An organizational chart is inappropriate for this type of project.
Q <sub>19</sub>		Assigning inappropriate tasks	Assigning wrong or incomplete tasks.
Q <sub>20</sub>		Absence of an HSE safety officer	Absence of the HSE officer on the worksite during the operation.



No.	Groups	Factors	Descriptions/definitions
Q21		Absence of workshop supervisor	Absence of the worksite supervisor during the operation.
Q22		Lack of training	The workforce is not professionally trained.
Q23		Improper working hours	Performing operations at inappropriate hours.
Q24		Physical defects	Occupational medicine is not done for the workforce and the worker does not have a work permit.
Q25		Fear – stress	Fear or stress in performing executive operations.
Q26		Distractions	The desired force is forgetful.
Q27	Individual activities	carelessness	Jokes or the like.
Q28		Variety of work	Performing various tasks with a limited number of personnel.
Q29		Fatigue	Incompatibility of the duration of work with the type of work.
Q30		Improper learning	The inability of the force to learn.
Q31		Improper temperature	Inadequate air temperature during the operation.
Q32	Environmental conditions	Improper sound	Inadequate noise or error signals.
Q33		Inadequate humidity	Inadequate air humidity during operations.
Q34		Inadequate lighting	Inadequate lighting during executive operations.
Q35		Failure to implement a fire alarm system	Implementation of a fire alarm system in the place of storage of incendiary cases.
Q36	Relief and secure	Lack of firefighting	Deployment of firefighting less than 5 minutes from the project site.
Q37		Lack of emergency medical teams	Deployment of relief teams less than 5 minutes from the project site.
Q38		Lack of safety equipment	Deployment of safety equipment required in the project by the type of executive operations.
Q39		Excessive reliance on technology	Given the lack of development of artificial intelligence and the reliability of technology, the system should not be left alone.
Q40	Technology	Technology does not conform to existing conditions	Using technology in similar processes regardless of available variables.
Q41		Lack of familiarity with technology	Lack of familiarity with technology, both in choosing and managing it.

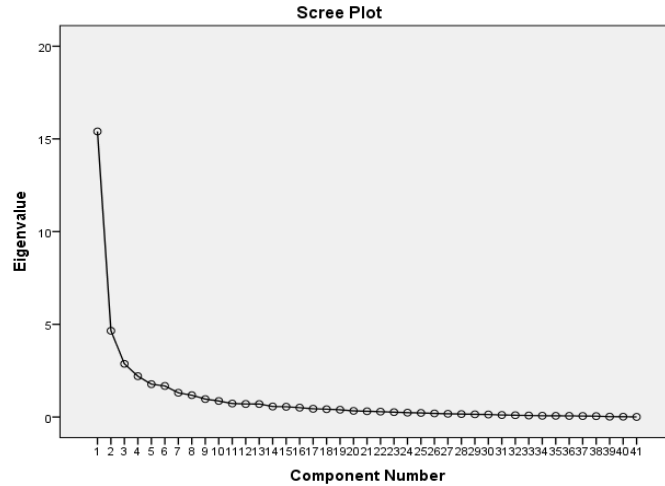
285 **3.2. Empirical Questionnaire survey**

286 The construct validity of the questionnaire was confirmed using factor analysis via SmartPLS  
287 software. In this research, exploratory factor analysis (EFA) was first carried out, followed by  
288 confirmatory factor analysis (CFA) in trying to validate the generated factor groupings. It is typical  
289 to utilize CFA using the same data as the EFA. Using the same data helps to demonstrate the  
290 model's robustness (Neumann et al., 2017).

291 To perform factor analysis using the principal components analysis method and to prove the  
292 data correlation matrix in the population is not zero, the sampling adequacy index (KMO value)  
293 and Bartlett's test of sphericity were used. The results showed that the index (KMO value) is 0.859  
294 and the Chi squared value calculated for Bartlett's sphericity test is statistically significant  
295 (sig<0.01). This means that the unity of the correlation matrix was rejected and the data is sufficient  
296 for factor analysis and sample size (Table 5). In addition, the Pebble diagram (Figure 2) is provided  
297 as one of the most traditional graphical methods for selecting the appropriate number of clustered  
298 factors from the allowable eigenvalues. As can be seen in Figure 2, after the tenth factor, the slope  
299 of the graph is horizontal and the addition of the tenth factor did not have much effect on increasing  
300 the variance. Therefore, the graph shows the number of 2 extractable factors (with eigenvalues  
301 greater than 1), which explains 78.102% of the total variance.

302 **Table 5.** Bartlett's test of sphericity and KMO scale of incidents caused by human errors

Bartlett's test of sphericity			KMO value (index)
Sig.	df	approx. Chi squared	KMO measure of sampling adequacy
0/001	820	5925/486	0/859



303

304 **Figure 2.** Pebble diagram related to the extracted factors of the scale of incidents caused by

305

human errors

306

307 Moreover, inclined rotation was used to extract and name the factors due to the positive  
 308 correlation of the factors. The results of inclined rotation showed that the first factor 37.566, the  
 309 second factor 11.345, the third factor 6.997, the fourth factor 5.367, the fifth factor 4.320, the sixth  
 310 factor 4.087, the seventh factor 3.189, the eighth factor 2.871 and the ninth factor 2.359 and in  
 311 total, all factors together explain 78.102 % of the total variance (Table 6). In total, all 41 items had  
 312 a factor loading of at least 0.4 (Table 7); it means that all items on the scale have a significant  
 factor loading.

313

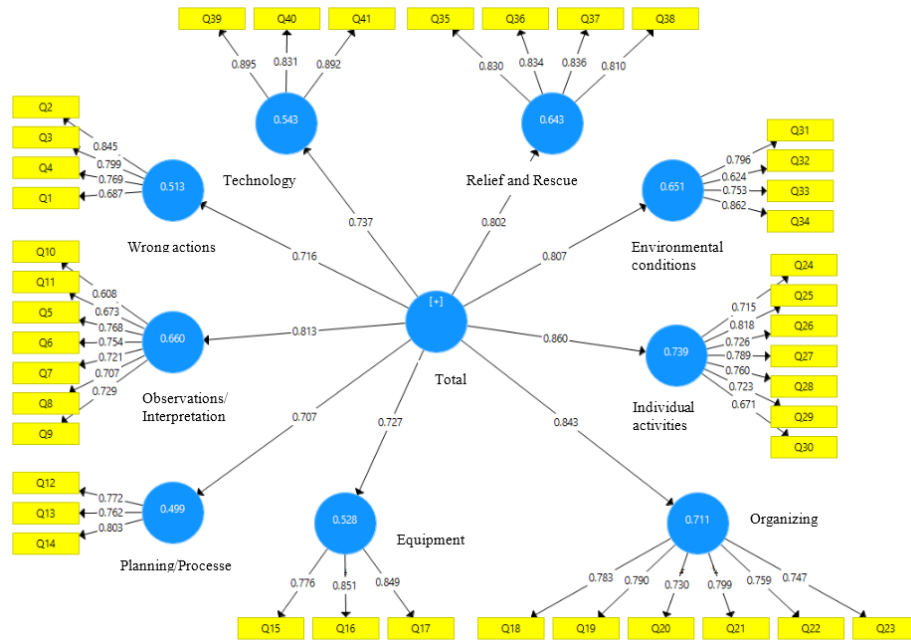
**Table 6.** Values of eigenvalue and variance explained by each factor extracted by factor analysis

<b>Factors</b>	<b>Eigenvalue</b>	<b>% of variance explained</b>
Wrong actions	15.402	37.566
Observations/Interpretations	4.652	11.345
Planning/Processes	2.889	6.997
Equipment	2.200	5.367
Organizing	1.771	4.320
Individual activities	1.676	4.087
Environmental conditions	1.307	3.189
Relief and secure	1.177	2.871
Technology	1	2.359

**Table 7.** Factorial structure matrix of the scale of incidents caused by human errors

Factors	Factor Loadings								
	1	2	3	4	5	6	7	8	9
Q <sub>1</sub>									0.811
Q <sub>2</sub>									0.742
Q <sub>3</sub>									0.592
Q <sub>4</sub>									0.405
Q <sub>5</sub>	0.922								
Q <sub>6</sub>	0.923								
Q <sub>7</sub>	0.892								
Q <sub>8</sub>	0.865								
Q <sub>9</sub>	0.962								
Q <sub>10</sub>	0.886								
Q <sub>11</sub>	0.711								
Q <sub>12</sub>								0.743	
Q <sub>13</sub>								0.843	
Q <sub>14</sub>								0.667	
Q <sub>15</sub>						0.783			
Q <sub>16</sub>						0.812			
Q <sub>17</sub>						0.748			
Q <sub>18</sub>			0.672						
Q <sub>19</sub>			0.603						
Q <sub>20</sub>			0.628						
Q <sub>21</sub>			0.597						
Q <sub>22</sub>			0.652						
Q <sub>23</sub>			0.626						
Q <sub>24</sub>		0.708							
Q <sub>25</sub>		0.783							
Q <sub>26</sub>		0.833							
Q <sub>27</sub>		0.826							
Q <sub>28</sub>		0.641							
Q <sub>29</sub>		0.797							
Q <sub>30</sub>		0.675							
Q <sub>31</sub>					0.695				
Q <sub>32</sub>					0.779				
Q <sub>33</sub>					0.811				
Q <sub>34</sub>					0.840				
Q <sub>35</sub>				0.798					
Q <sub>36</sub>				0.855					
Q <sub>37</sub>				0.838					
Q <sub>38</sub>				0.779					
Q <sub>39</sub>							0.708		
Q <sub>40</sub>							0.726		
Q <sub>41</sub>							0.747		

316 Moreover, Figure 3 lists the factor loadings related to all questions. Since the values of all  
 317 factor loadings of the questions are larger than (0.3), it can be concluded that the model manifests  
 318 good fitness. In addition, the values related to convergent validity, model reliability and fitness  
 319 indices have been reported in Table 7 and the values related to divergent validity calculations of  
 320 the model have been presented in Table 8.



321  
 322 **Figure 3.** Factor loadings of the questions listed in the research questionnaire

323 According to Table 8, the values of Cronbach's alpha and combined reliability for all  
 324 variables are greater than (0.7) also, the value of convergent validity is greater than (0.5) for all  
 325 variables, so the reliability of the model is favorable. The obtained values for  $R^2$  indicate the  
 326 optimal fitness of the structural model. In addition, according to the value of  $Q^2$ , it can be  
 327 concluded that the prediction power of the model is good. In general, the model can predict the  
 328 relevant values well. On the other hand, the values obtained for variable F2 indicate that the effect  
 329 size of the model is desirable. Also, the value of (GOF) obtained is 0.486, which indicates the  
 330 desirable fitness of the model.

331

**Table 8.** Indicators of convergent validity, model reliability and fitness test

Variables	Cronbach's alpha	Combined reliability	Convergent validity AVE	Communality values	R <sup>2</sup>	Q <sup>2</sup>	F <sup>2</sup>	GOF
Wrong actions	0.870	0.858	0.604	0.364	0.513	0.281	1.055	0.486
Relief and Rescue	0.847	0.897	0.685	0.469	0.643	0.409	1.800	
Planning/Processes	0.700	0.822	0.607	0.368	0.499	0.278	0.998	
Equipment	0.767	0.865	0.682	0.465	0.528	0.337	1.118	
Technology	0.844	0.906	0.762	0.580	0.543	0.392	1.189	
Organizing	0.861	0.896	0.591	0.349	0.711	0.388	2.466	
Environmental conditions	0.758	0.847	0.583	0.399	0.651	0.353	1.863	
Individual activities	0.865	0.897	0.554	0.306	0.739	0.378	2.836	
Observations/Interpretations	0.836	0.877	0.505	0.255	0.660	0.304	1.945	

332

According to the values obtained in Table 9, the values of the root (AVE) on the main

333

diameter of the matrix are greater than the lower values of each cell, so the divergent validity

334

model is acceptable.

335

**Table 9.** Divergent validity of the model using Fornell and Larker values

No.	Groups	1	2	3	4	5	6	7	8	9
1	Wrong actions	0.777								
2	Relief and Rescue	0.446	0.827							
3	Planning/Processes	0.491	0.509	0.779						
4	Equipment	0.425	0.454	0.516	0.826					
5	Technology	0.430	0.754	0.442	0.451	0.873				
6	Organizing	0.564	0.581	0.496	0.683	0.535	0.769			
7	Environmental conditions	0.507	.755	0.553	0.552	0.661	0.569	0.764		
8	Individual activities	0.517	0.629	0.509	0.607	0.565	0.742	0.634	0.744	
9	Observations/Interpretations	0.705	0.541	0.668	0.518	0.456	0.559	0.547	0.626	0.710

336

Finally, the questionnaire was prepared based on a 5-point Likert scale of measurement and

337

distributed among experts. This study used a purposive sampling method in selecting the

338

respondents to the survey, which was conducted by other researchers for similar research questions

339

(Tamošaitienė et al., 2021). According to the subject of the study, the statistical population

340

includes architects, engineers, construction management specialists, insurance experts and HSEE

341

experts of the company of the Industrial Parks. Experts and respondents were selected based on

342 relevant hands-on working experience (Malek et al., 2020). In the present study, the sample size  
 343 was calculated using Cochran's sample size formula. Cochran's formula used is provided as follows  
 344 (Cochran, 1954):

$$345 \quad n_0 = \frac{Z^2 pq}{e^2} \quad eq.1$$

346 p is the proportion of the population (0.5) and q is 1-p (0.5). e is the margin of error (0.05)  
 347 and Z is the standard error (1.96). If the population is small, it is written as follows (equation 2):

$$348 \quad n = \frac{n_0}{1 + \frac{n_0 - 1}{N}} \quad eq.2$$

349 N is the population size and  $n_0$  is Cochran's sample size. 220 people were considered as the  
 350 population of the study based on Cochran's formula, 140 is the calculated Cochran's sample size  
 351 and the same number of blank questionnaires were distributed, of which 136 completed  
 352 questionnaires were received. Table 10 shows the respondents background in the questionnaire  
 353 survey. The response rate of the survey was found as 97.14%. The available sampling method was  
 354 used in this study.

355 **Table 10.** Respondents' background of the empirical questionnaire survey

Feature	Code	Number (%)
Gender	Men	104 (76.5)
	Women	32 (23.5)
Age	<30 years old	15 (11)
	30–50 years old	52 (38.2)
	>50 years old	69 (50.8)
Educational level	Bachelor's degree	59 (43.4)
	Master's degree	54 (39.7)
	PhD degree	23 (16.9)
Tenure in the construction sector	<10 years	34 (25)
	10–20 years	76 (55.9)
	>20 years	26 (19.1)
Tenure in safety management	<10 years	73 (53.7)
	10–20 years	39 (28.7)
	>20 years	24 (17.6)
Job position	Architect	5 (3.7)
	Engineer—Civil, Electrical, and Mechanical	59 (43.4)
	Safety Manager	13 (9.5)
	General Manager—insurance	12 (8.8)
	Project Manager	11 (8)
	Senior Project Manager	31 (22.9)
	University Professor	5 (3.7)

#### 356 4. Results of the Fuzzy Delphi Survey

357 The analysis of this study was performed using SPSS statistical software at two levels of  
358 descriptive and inferential statistics. In the descriptive statistics section, statistical characteristics  
359 such as frequency, percentage, mean and standard deviation have been used, and in the inferential  
360 statistics section, the Kolmogorov-Smirnov test, single-sample t-test and Friedman test have been  
361 used.

362 A prerequisite for performing parametric tests is the normal statistical distribution of  
363 variables. In general, it can be said that parametric tests are based on mean and standard deviation.  
364 Now, if the distribution of society is not normal, it is not possible to deduce the results correctly.  
365 Therefore, by performing this test, if the significance (Sig) is zero, the normality of the distribution  
366 is concluded. Table 11 shows the test of the assumption of the normality of the population  
367 distribution. As shown in Table 11, the value of significance level in the whole research  
368 questionnaire is more than (0.05), therefore, the null hypothesis in this variable is confirmed at the  
369 95% confidence level and the data distribution in the research variable follows the normal  
370 distribution. Therefore, parametric tests are used to examine the data.

371 **Table 11.** Kolmogorov-Smirnov test to assess the normality of research data

Variable	Significance level	Statistics	p-value	Variable	Test results
Factors influencing the incidence of accidents caused by human error in the industrial areas of Iran	<b>0.246</b>	<b>1.023</b>	<b>0.05</b>	H <sub>0</sub>	<b>H<sub>0</sub> rejected</b>

H<sub>0</sub>: The data of the research questionnaire have a normal distribution

H<sub>1</sub>: The data of the research questionnaire do not have a normal distribution

#### 372 4.1. Factors affecting the occurrence of accidents caused by human errors

373 According to Table 12, the mean value of the total questionnaire on effective factors in  
374 learning from accidents caused by human error is equal to (4.219) and the mean value of the



375 dimensions of the questionnaire in terms of wrong actions is (4.367), observations/interpretations  
 376 (4.279), planning/Processes (4.289), Equipment (4.321), Organizing (4.216), Individual activities  
 377 (4.171), Environmental conditions (4.150), Rescue (4.068) and Technology (4.105). Since the  
 378 value of the P-Value is less than the value of (0.05), therefore, the identified factors in the nine  
 379 groups and the whole questionnaire are significantly different from the test value, i.e., the number  
 380 (3) and is in the above-mean state. On the other hand, considering that the upper and lower limits  
 381 of the positive confidence interval have been obtained, it can be concluded that all factors and  
 382 groups used are strong in effective factors in the occurrence of accidents caused by human error  
 383 in the implementation of Industrial Parks in Iran.

384 **Table 12.** The results of the single-sample t-test

Dimensions	Number	Mean	Standard deviation	Test Value = 3			Lower limit	Upper limit
				t	df	P-Value		
Wrong actions	136	4.367	0.546	29.406	135	0.00	1.284	1.469
Observations / Interpretations	136	4.279	0.506	29.452	135	0.00	1.193	1.365
Planning / Processes	136	4.289	0.577	26.201	135	0.00	1.191	1.387
Equipment	136	4.321	0.591	26.055	135	0.00	1.220	1.421
Organizing	136	4.216	0.627	22.634	135	0.00	1.110	1.323
Individual activities	136	4.171	0.627	21.780	135	0.00	1.064	1.277
Environmental conditions	136	4.150	0.651	20.601	135	0.00	1.040	1.261
Relief and Rescue	136	4.068	0.740	16.830	135	0.00	0.942	1.193
Technology	136	4.105	0.757	17.015	135	0.00	0.976	1.233
The whole questionnaire	136	4.219	0.485	29.272	135	0.00	1.136	1.301

385 **4.2. Importance of effective factors in the occurrence of accidents caused by human errors**

386 The results of Table 13 show that the significance level for each of the identified groups and  
 387 factors is less than the threshold of 0.05 ( $P < 0.05$ ), therefore, it can be concluded that there is a  
 388 significant difference between the rank of groups and the factors identified in the occurrence of  
 389 accidents caused by human error in the IPCPs.

390 **Table 13.** Friedman test results (the significant result of groups and factors of human errors)

Questionnaire	Chi-square	Degree of freedom	Significance level	Test results
9 groups	51.959	8	0.000	H <sub>0</sub> Rejected
Identified factors	183.657188.671	40	0.000	H <sub>0</sub> Rejected

H<sub>0</sub>: The average rank is equal  
H<sub>1</sub>: The average rank is not equal

391  
392 Based on the results of Table 14 in the Friedman test ranking, rank 1 has been allocated to  
393 the groups of wrong actions with a mean rank of (5.96), rank 2 to equipment with a mean rank of  
394 (5.45), rank 3 to planning/processes with a mean rank of (5.43), Rank 4 to the group of  
395 Observations/Interpretations with average rating (5.20), Rank 5 to the group of Organizing with a  
396 mean rank of (5.05), Rank 6 to the group of Individual activities with a mean rank of (4.65), rank  
397 7 to Conditions Environment with a mean rank of (4.61), ranks 8 to technology with a mean rank  
398 of (4.40) and rank 9 to the group of rescue with a mean rank of (4.25).

399 Table 11 also shows that in the Friedman test ranking, time factors with a mean rank of  
400 (24.74), delayed interpretation with a mean rank of (24.36), incorrect diagnosis/prediction with a  
401 mean rank of (24.22), A tool with a mean rank of (23.96), failure to perform the necessary controls  
402 with a mean rank of (23.03), respectively, were identified as 5 factors affecting the incidence of  
403 human errors in the implementation of IPCPs in Iran. Also, factors of unfamiliarity with  
404 technology with a mean rank of (18.27), lack of safety equipment with a mean rank of (18.36),  
405 inappropriate learning with a mean rank of (18.46), incorrect reasoning with a mean rank of  
406 (17.99), non-implementation of fire alarm system with a mean rank of (17.91), respectively, we're  
407 recognized as the least effective factors among the studied factors.

408

409  
410

**Table 14.** Results of the Friedman test for ranking the groups and factors of human errors identified in the occurrence of human errors

No.	Group (Mean rank)	Group rank	Factors	Mean rank	Rank in the group	Overall rank
1	Wrong actions (5.93)	1	Time	24.74	1	1
2			operational	22.99	2	6
3			Tools	23.96	2	4
4			Place	21.60	4	15
5			Improper quality control	20.40	6	27
6	Observations / Interpretations (5.18)	4	Ignore the symptoms	20.72	5	25
7			False argument	17.99	7	40
8			Incorrect diagnosis / prediction	24.22	2	3
9			Lack of access or defect in observations	20.78	4	24
10			Delayed interpretation	24.36	1	2
11	Planning / Processes (5.40)	3	Failure to perform the necessary controls	23.03	3	5
12			Improper design	21.53	2	16
13			Prioritization / scheduling error	22.75	1	7
14	Equipment (5.42)	2	Improper construction method	21.37	3	19
15			Equipment failure	21.64	3	14
16			Software error	22.56	2	9
17	Organizing (5.03)	5	Equipment deduction	22.57	1	8
18			Improper chart	22.05	2	12
19			Assigning inappropriate tasks	19.41	5	33
20			Absence of HSE safety officer	21.39	4	18
21			Absence of workshop supervisor	19.07	6	34
22	Individual activities (4.62)	6	Lack of training	22.42	1	10
23			Improper working hours	21.70	3	13
24			Physical defects	20.09	5	29
25			Fear - stress	20.28	4	28
26			Distractions	19.43	5	32
27			carelessness	21.22	2	20
28			Variety of work	20.85	3	23
29			Fatigue	22.25	1	11
30			Improper learning	18.86	6	37
31		7	Improper temperature	18.89	4	35

No.	Group (Mean rank)	Group rank	Factors	Mean rank	Rank in the group	Overall rank
32	Environmental conditions (4.58)		Improper sound	19.64	3	30
33			Inadequate humidity	21.48	1	17
34			Inadequate lighting	20.90	2	22
35			Failure to implement fire alarm system	17.91	4	41
36	Relief and secure (4.32)	9	Lack of firefighting	20.99	1	21
37			Lack of emergency medical teams	18.68	2	36
38			Lack of safety equipment	18.36	3	38
39			Excessive reliance on technology	19.44	2	31
40	Technology (4.51)	8	Technology does not conform to existing conditions	20.61	1	26
41			Lack of familiarity with technology	18.27	3	39

## 411 5. Discussion of Analytical Results

412 Nine groups have been identified based on the background of the research and the opinions of  
413 experts, for this purpose, a fuzzy Delphi survey was adopted. As the results of the present study  
414 show, in the group of wrong actions, time and instrumental factors are the most effective factors  
415 in this group in the occurrence of accidents caused by human errors in the construction industry.  
416 Doing the right thing at the wrong time can spell disaster in industrial projects. In the group of  
417 observations/interpretations, delayed interpretation and incorrect diagnosis/prediction are among  
418 the most important causes of accidents. Weak management and supervision can be one of the  
419 causes of delayed interpretation and incorrect diagnosis/prediction, which can be solved by  
420 continuous control. In planning/processes, rank 1 is for prioritization/scheduling errors, which can  
421 be caused by poor management. In equipment, the rank is 1 for equipment deduction; in  
422 organizing, it ranks 1st for lack of training; in individual activities, the rank is 1 for fatigue which  
423 could be due to a lack of financial resources. In environmental conditions, the rank is 1 for  
424 inadequate humidity which could be due to a lack of supervision. In relief and secure, the rank is

425 1 for lack of firefighting; in technology, the rank is 1 for technology does not conform to existing  
426 conditions which could be due to a lack of financial resources. According to rank 1, the main sub-  
427 factors are two important weaknesses: mismanagement and weak supervision and lack of financial  
428 resources; by strengthening these two issues, human error can be greatly reduced.

429         The results of this study are consistent with the results of previous studies. For example,  
430 Azhdari et al. (2016) have concluded that increasing the effectiveness of employee training and  
431 improving monitoring of employee performance plays a key role in reducing the incidence of  
432 human error events in the industry. Morais et al. (2018), factors such as inadequate skills, lack of  
433 sufficient information, inadequate quality control, inadequate communication, inadequate working  
434 hours, design problems, and management issues were identified as causes of human errors. Amiri  
435 et al. (2014) also found that factors such as burnout and heat are considered serious factors in the  
436 occurrence of accidents in construction industry projects. Xu et al. (2019) acknowledged that  
437 reducing the risks of human errors among construction workers lies strongly in the issue of  
438 education. The results of their research also showed that age, experience, and site environment are  
439 influential in the occurrence of accidents. Dhalmahapatra et al. (2019) have also considered the  
440 issue of lack of proper interaction between humans and technology in the occurrence of accidents  
441 caused by human errors.

442         Considering the results of previous research and the results obtained in the present study, it  
443 can be pointed out that in recent years, many efforts have been made by researchers to reduce  
444 human errors in the construction industry. However, the key stakeholders of construction projects  
445 (employers and contractors) to improve site safety performance in the construction industry still  
446 encounter many unknown ambiguities and challenges. At the same time, increasing site safety  
447 performance in the construction industry, which is one of the main factors in the success of

448 projects, is a vital issue in the development of the construction industry. In this regard, a thorough  
449 study of the factors affecting the incidence of human errors, especially in developing countries, is  
450 far more essential. Focusing on the key contributing factors such as wrong actions,  
451 observations/interpretations, planning/processes, equipment, organizing, individual activities,  
452 environmental conditions, rescue, and technology, can be a positive step taken forward in reducing  
453 the existing practice gaps and improving site safety issues in the construction process. Due to their  
454 high ability to combat various scientific problems, artificial intelligence and deep learning method  
455 can be useful and applied in human error analysis for making improvements (Sorkhabi et al., 2022;  
456 Park et al., 2022).

## 457 **6. Conclusions and research implications**

458 This study aimed to identify and investigate the factors affecting the incidence of human errors in  
459 IPCPs based in Iran. For this purpose, effective factors in the incidence of human errors were  
460 extracted by reviewing the research literature, then it was monitored by performing four rounds of  
461 the fuzzy Delphi survey. Finally, forty-one important and influential factors were identified. The  
462 researcher-made questionnaire was developed based on forty-one factors classified into nine main  
463 groups including wrong actions, observations/interpretations, planning/processes, equipment,  
464 organizing, individual activities, environmental conditions, rescue, and technology, based on a 5-  
465 point Likert scale of measurement. The face and construct validity and the reliability of the  
466 questionnaire were examined and confirmed. Then an empirical survey questionnaire was  
467 distributed among the experts. Based on the Cochran sample size formula and using the available  
468 sampling method, 136 construction experts in Iran were selected as the statistical sample. After  
469 collecting the questionnaires, SPSS software was used to analyze the data and opinions gleaned.  
470 The findings of the study indicated that the identified factors in the occurrence of accidents caused

471 by human errors in the IPCPs are in the above-mean situation, and all the identified factors can be  
472 considered strongly key factors in the occurrence of accidents caused by human errors in IPCPs in  
473 Iran. In addition, in the group rankings, the groups of wrong actions, equipment,  
474 planning/processes, observations/interpretations, organizing, individual activities, environmental  
475 conditions, technology, and rescue, were ranked from 1 to 9, respectively. In addition, in ranking  
476 the identified factors by considering all groups, time factors, delayed interpretation, incorrect  
477 diagnosis/prediction, tool, and failure to perform the necessary controls respectively were  
478 recognized as the five most effective factors in the occurrence of human errors in the  
479 implementation of IPCPs in Iran.

480 In terms of practical implications related to the results of this study, to reduce human errors  
481 in the construction industry, especially in developing countries, it is recommended to determine  
482 the relevant factors in advance and to set standards and protocols for organizations. A structured  
483 definition of safety management dramatically increases the chance of reducing and controlling  
484 human errors within the construction industry.

485 In terms of theoretical implications, this study helps to better manage site safety performance  
486 in construction projects by identifying the significant factors influencing the incidence of human  
487 errors in the implementation of IPCPs from a quantitative perspective - which, according to the  
488 authors' knowledge, has not been studied before. It demonstrates the control of the actions of  
489 people and equipment, as well as the proper planning of processes, allowing construction  
490 companies to help improve their effectiveness and productivity in site safety management. To  
491 succeed in effective safety management, construction companies may need proper organization,  
492 control of individual activities, improvement of environmental conditions, updating of the  
493 organization in terms of advanced technology application and increasing the facilities and

494 equipment of rescue in their companies for achieving better safety excellence. Hence, some of the  
495 perceived future research directions and guidelines for deepening the identified findings are  
496 provided as follows for reference: What are the specific managerial and environmental capabilities  
497 that will allow construction companies to perform better in terms of site safety performance? How  
498 can technology development and deployment help construction companies to succeed in  
499 improving site safety management? What are the possible human error reduction or prevention  
500 strategies that can be adopted by construction companies?

501 Future research studies could augment the generalizability of the survey results by increasing  
502 the number of construction experts involved to evaluate the identified factors in a similar study.  
503 However, as suggested by (Sarvari et al., 2020), it will also be valuable and interesting to compare  
504 the effective factors affecting the incidence of human errors according to the level and pace of  
505 development of the countries under investigation (developed versus developing) to capture any  
506 discerned similarities and differences behind. Finally, the results of this study can assist different  
507 major project stakeholders and site safety management personnel as effective decision facilitators  
508 in handling, reducing, and preventing any human errors prone to the occurrence of construction  
509 site accidents in future.

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